How Will Carbon Fiber Manufacturing Quadruple To Meet Market Demands

Presenter: Dr. Peter Witting
Sr. Process Technology Engineer
Harper International
Presented at: Carbon Fiber 2016

Introduction

Challenge: Carbon fiber applications for ground transportation exert market pressure towards increased capacity and lower cost.

How can our industry meet the demand?

Agenda

- **About Harper**
- Automotive Materials Usage
- Current Carbon Fiber Production Lines
- 10,000 Tons Per Year Carbon Fiber Lines
  - Space Requirements
  - Energy Consumption
  - Technical Challenges

About Harper

- Headquartered near Buffalo, NY
- An employee-owned company
- Onsite Technology Center
- Multi-disciplined engineering talent
  - Chemical
  - Ceramic
  - Mechanical
  - Electrical
  - Industrial
  - Process & Integration

Carbon Fiber Carbonization Process – Scales of Operation

Scale	Size Range (Tow-Band Width)	Capacity
Commercial Production Line	1000 – 4200 mm	500 - 4000 ton/year
Pilot Line	300 -1000 mm	20 - 100 ton/year
Microline	≤100 mm	Less than 10 ton/year
Scientific Line	Fractional tows (<1k or less than 1,000 filaments)	Less than 1 ton/year

Courtesy of Oak Ridge National Laboratory

Courtesy of Georgia Institute of Technology

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*Georgia tech has produced the highest tensile strength PAN based carbon fiber ever reported, and highest combination of strength and modulus ever reported, on their Harper Scientific Line.

http://www.news.gatech.edu/2015/07/22/innovative-method-improves-strength-and-modulus-carbon-fibers

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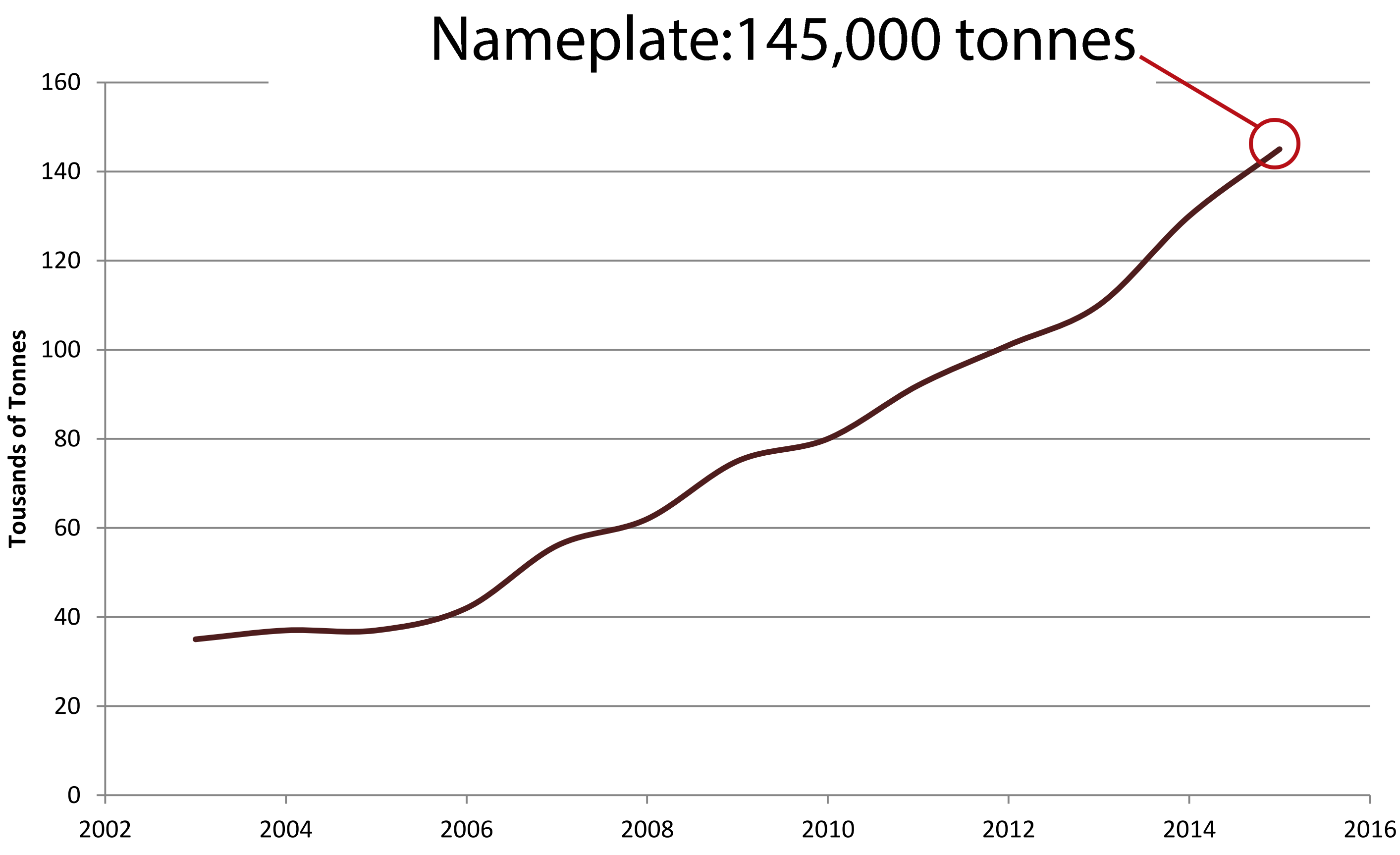
Historical PAN-based Carbon Fiber Supply



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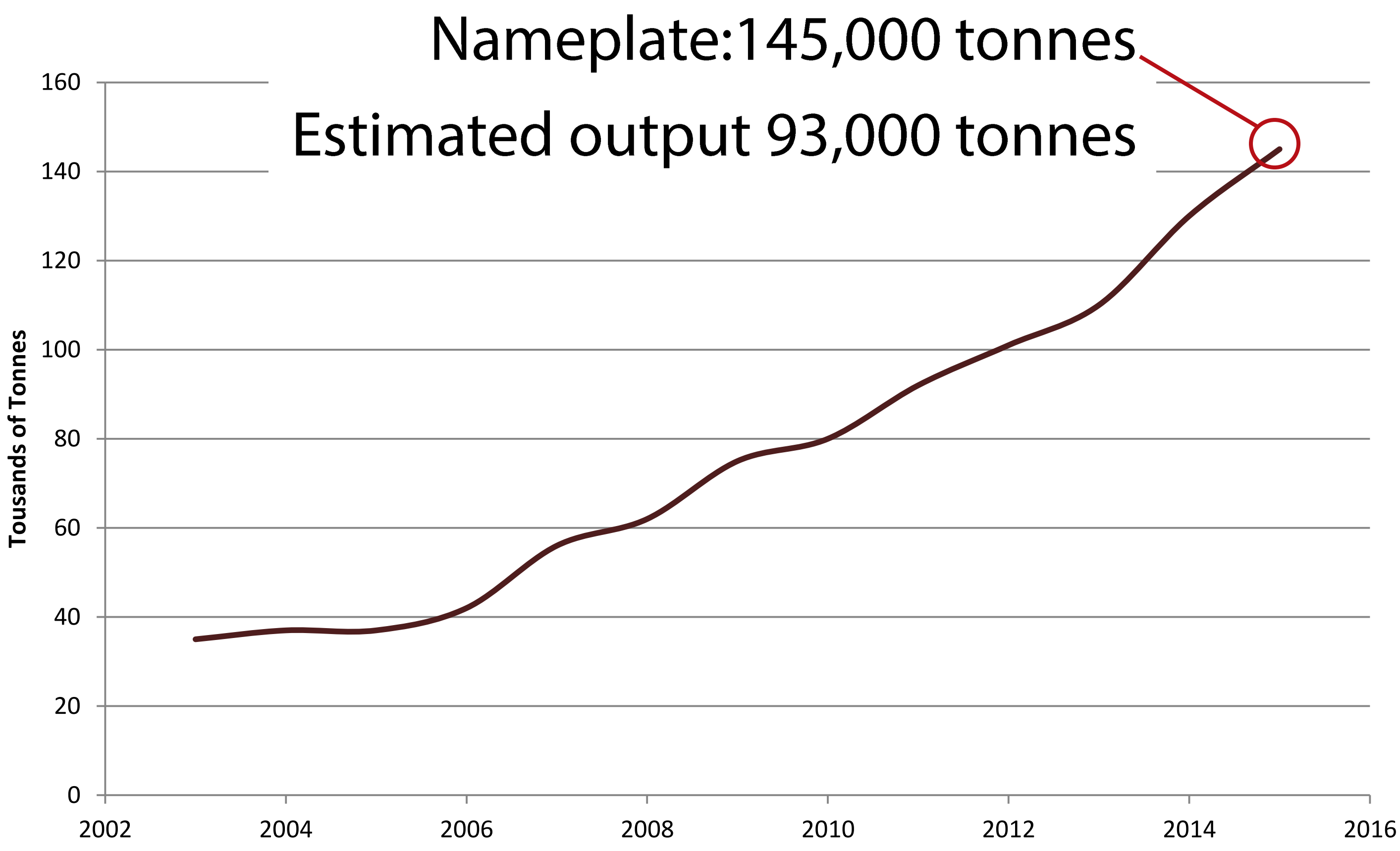

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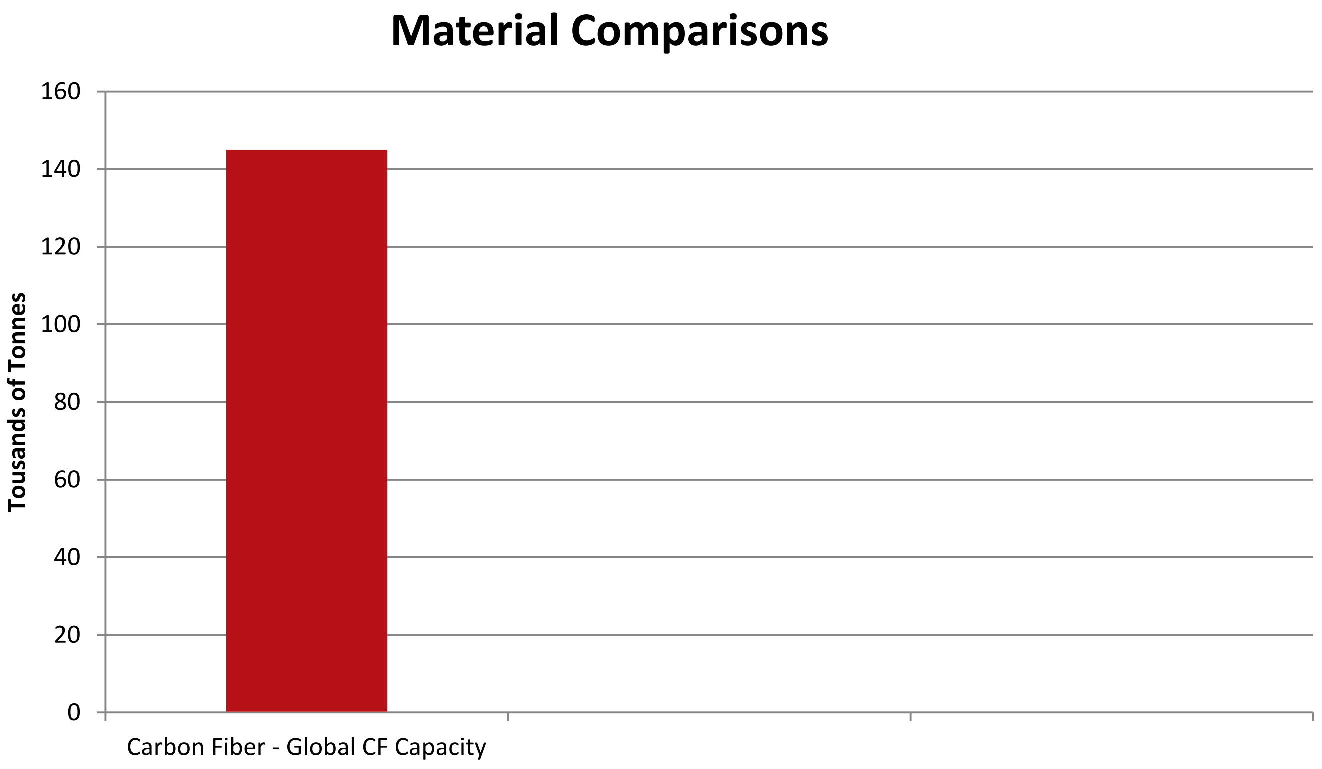
Global Carbon Fiber Capacity vs Automotive Material Demand



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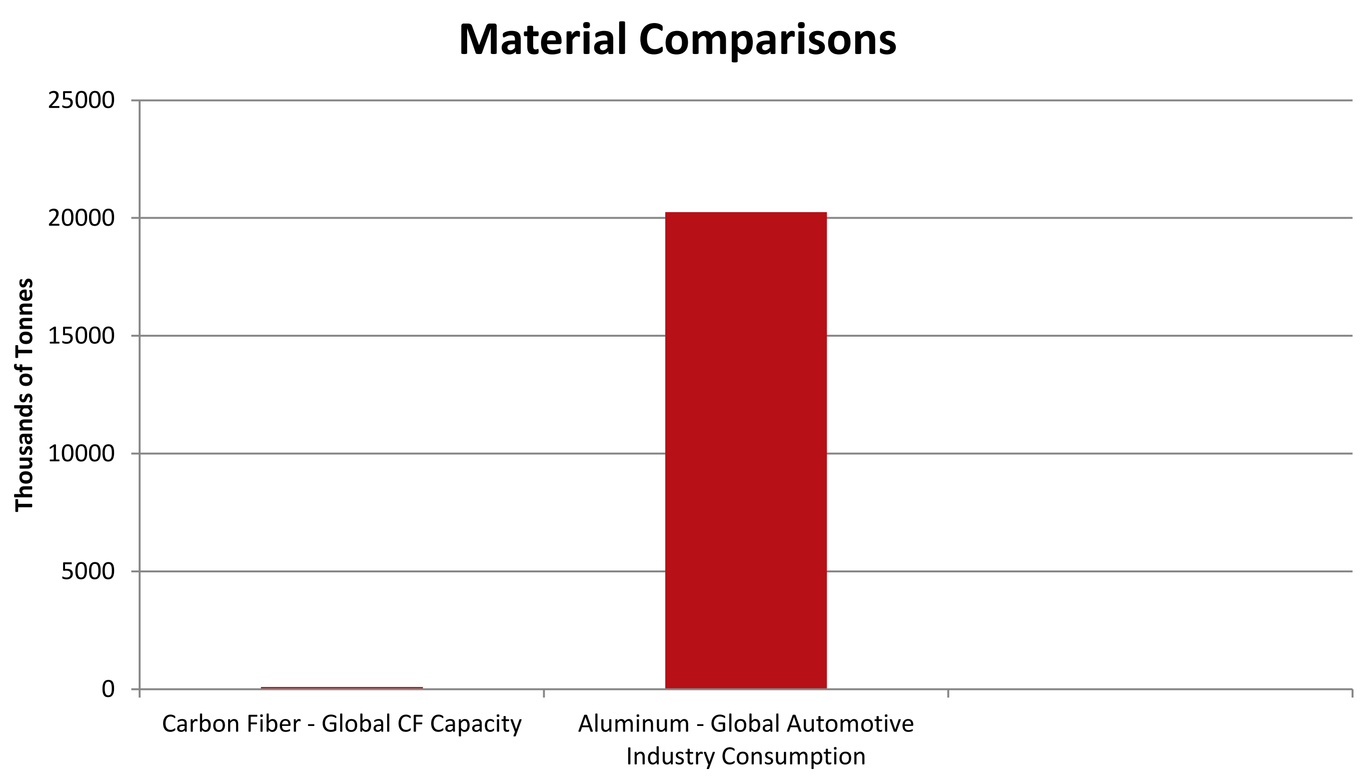

Source: http://www.aluminiumleader.com/economics/world_market/

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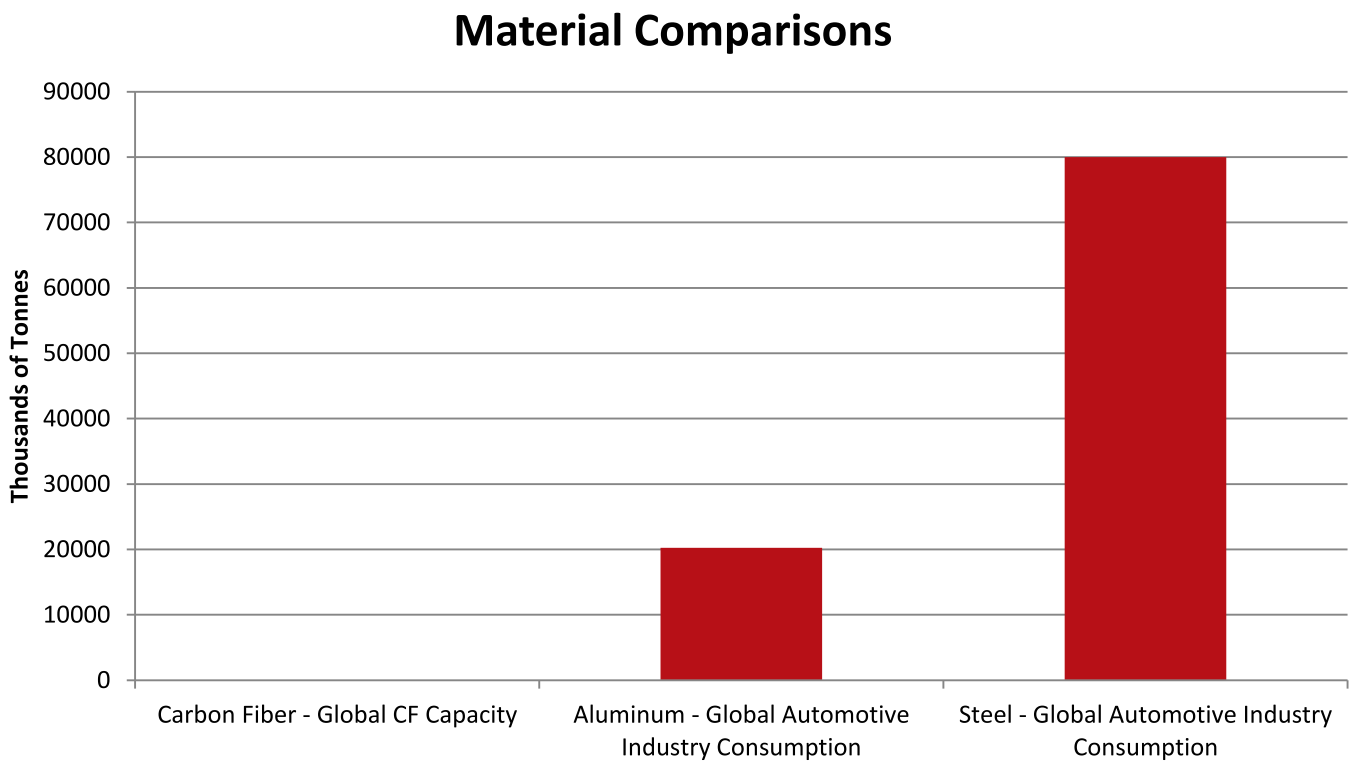

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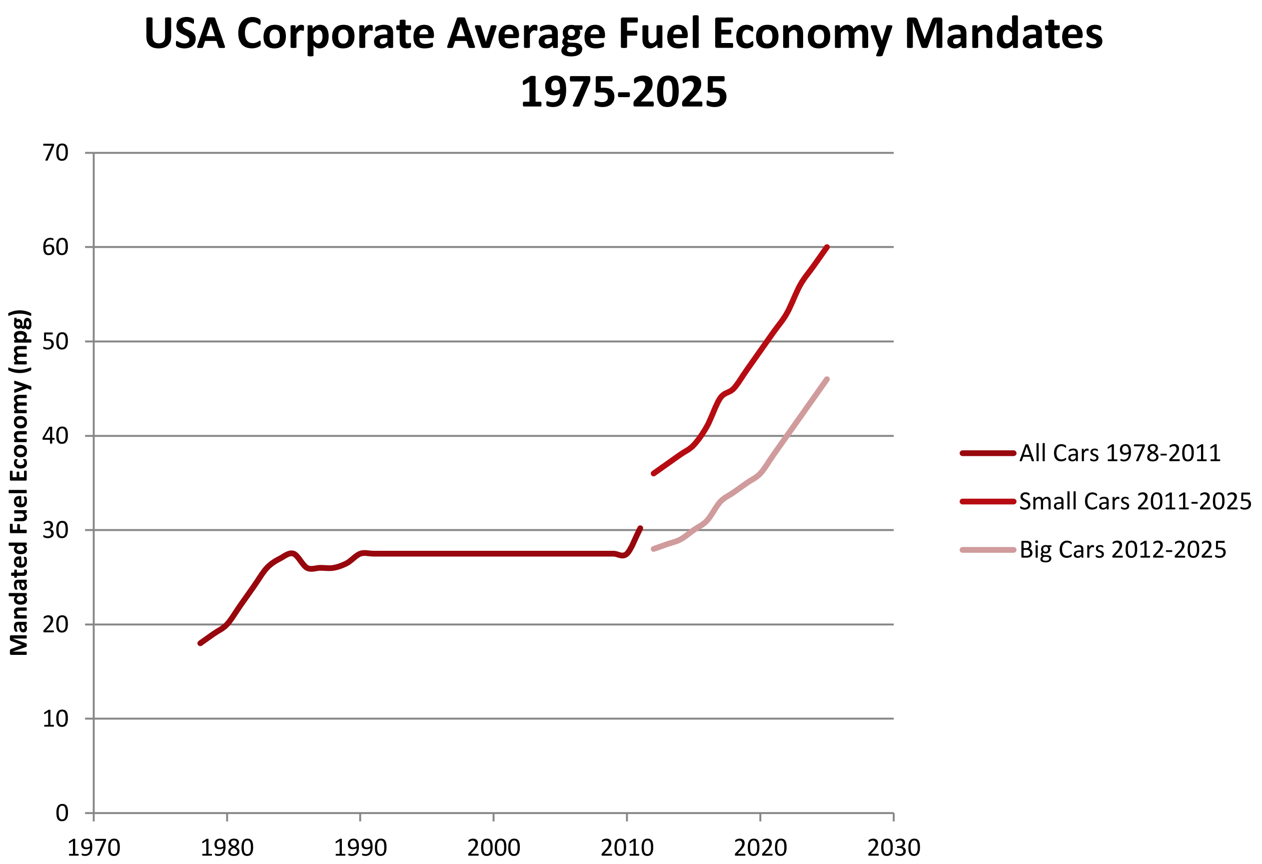
The Drive For Efficiency



Source: National Highway Traffic Safety Administration, http://www.nhtsa.gov/fuel-economy

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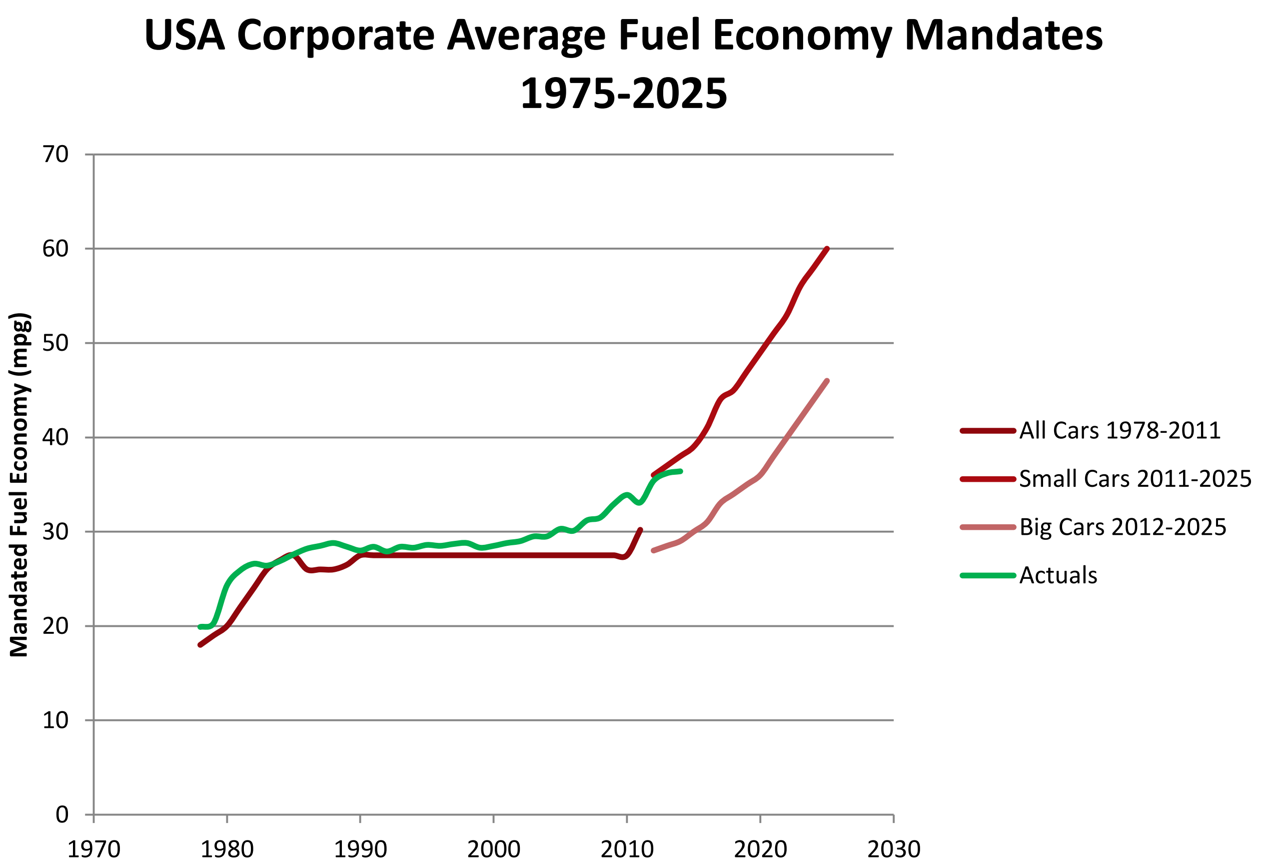

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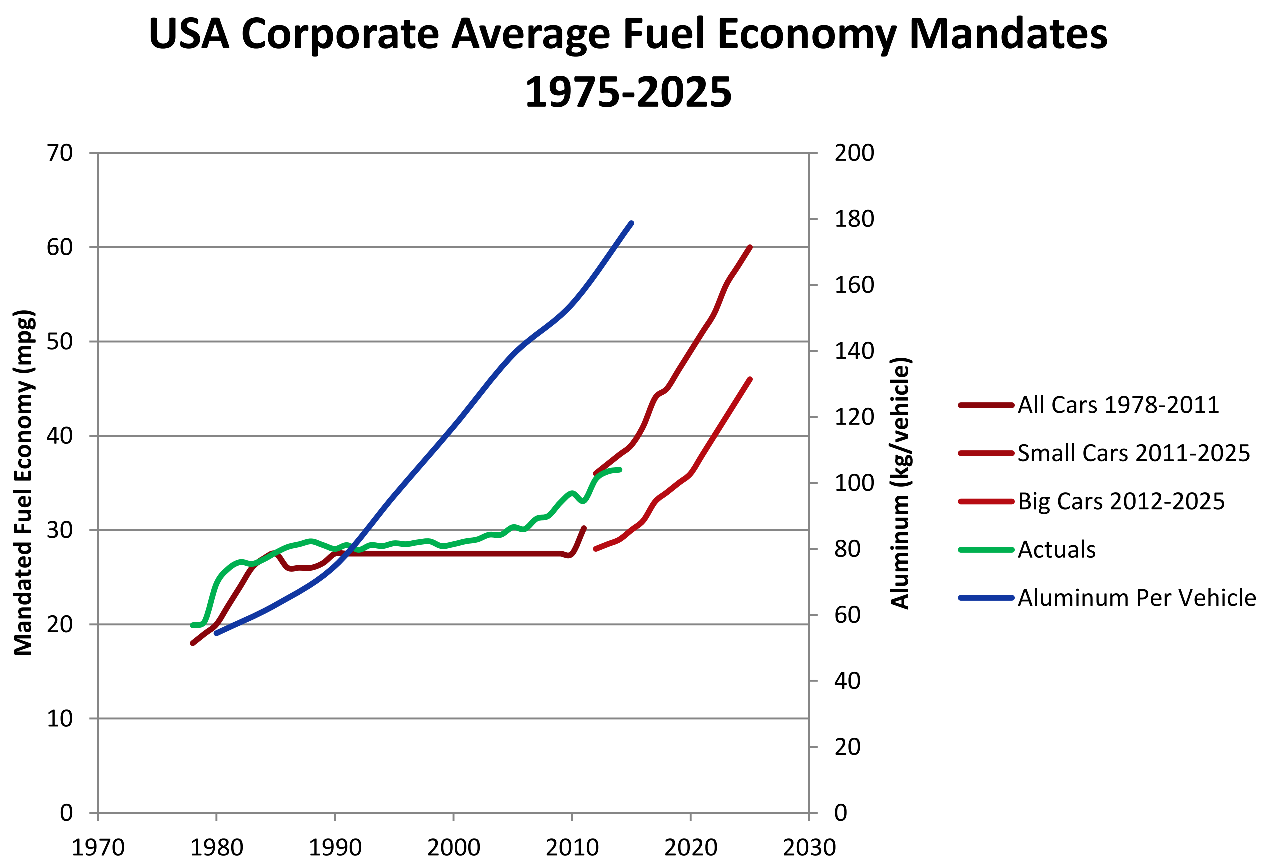

Source: 2015 North American Light Vehicle Aluminum Content Study, Ducker Worldwide, 2014

Example – C7 (2014+) Corvette Stingray

Every roof and hood – CFRP

Sources: plasancarbon.com; corvetteblogger.com; GM, Ford, and VW Annual Reports

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→ 8.2kg CF per Coupe

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Example – C7 (2014+) Corvette Stingray

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2014 Global Industry

- 87.9 Million Vehicles

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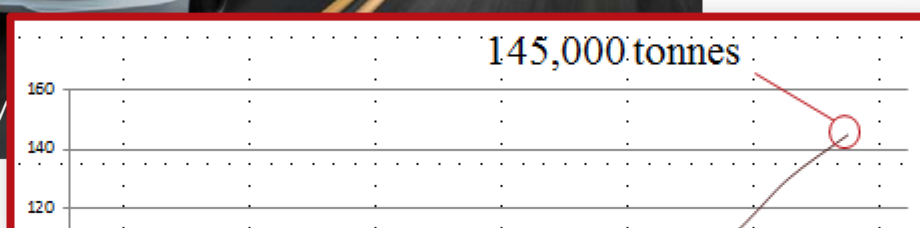

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Carbon Fiber – Current Production Lines

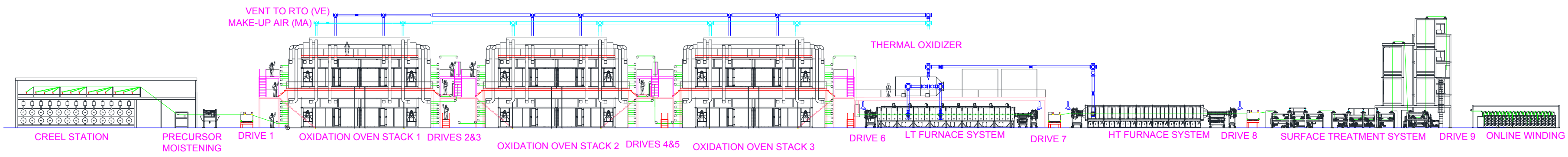
1500 to 2500 Tons Per Year

3 Meter Processing Width

3 Meter Wide Harper Oxidation Oven Section

Current Production Lines – Floor Space Requirements

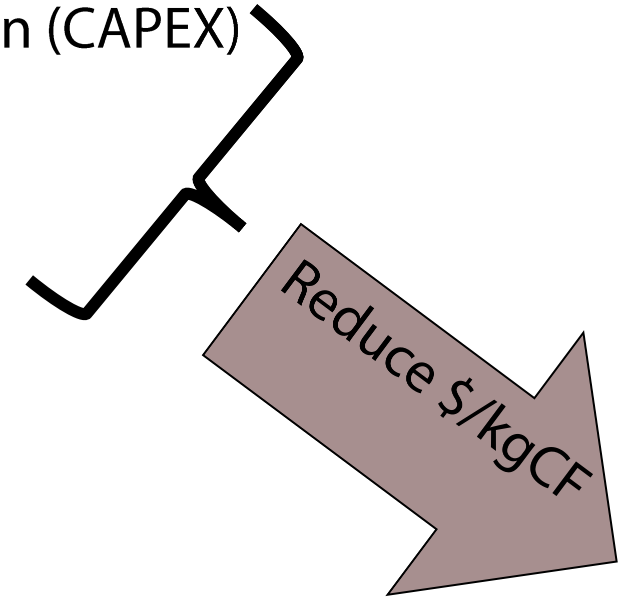
Up to 300 meters long



20 - 40 meters wide

Production Cost Drivers
$/kg Carbon Fiber

- PAN precursor
- Depreciation (CAPEX)
- Labor
- Energy



High Capacity
Plant Design

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- **10,000 Tons Per Year Carbon Fiber Lines**
  - Scale Up Scenarios
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  - Energy Consumption

Carbonization Line Scale Up

$$Production\ Rate = (Yield) \times \left(\frac{Mass}{Filament\ Length}\right) \times (Total\ Filaments) \times (Linespeed)$$

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- Annual capacity is Production Rate times the available hours per year

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Paths to 10,000 Tons/Year

	Filaments per mm	Linewidth m	Linespeed m/min	Tonnes/year
Baseline	2000	3	10	2000
Scaleup Factor	1.71	1.71	1.71	5
	3420	5.13	17.1	10000
Scaleup Factor	1.25	2.00	2.00	5
	2500	6.00	20.0	10000
Scaleup Factor	1.75	2.00	1.43	5
	3500	6.00	14.3	10000
Scaleup Factor	4.50	1.00	1.11	5
	9000*	3.00	10.5	10000

* Source: ORNL Low-Cost Carbon Fiber Process – April, 2016

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- This represents scalable technology

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Technical Challenges

Today
2,000 TPY
3 meters wide
10 m/min
2,500 filaments/mm

Tomorrow
10,000 TPY
5 or 6 meters wide
20 m/min
5,000 filaments/mm

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Technical Challenges

Today		Tomorrow
2,000 TPY		10,000 TPY
3 meters wide		5 or 6 meters wide
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2,500 filaments/mm		5,000 filaments/mm

- Wider lines

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  - Thermal and velocity uniformity across the width

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  - Access platforms

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  - Longer furnaces (cleaning, catenary)
  - Process off-gas extraction (pipes plugging; vent placements)
  - Faster developing upsets (broken tow, wrapping)
  - More frequent re-creeling or splicing

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  - Potentially increases required residence times
  - Increased potential for exothermic runaways
  - Drop in fiber mechanical properties
  - Cosmetic damage

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2,000 TPY
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Overall needs…

Technical Challenges

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2,000 TPY	10,000 TPY
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Overall needs…

→Greater process stability

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Technical Challenges

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Overall needs…

→Greater process stability

→Equipment thermal precision and reliability

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PAN Oxidation – Critical and difficult part of the process

"Like toasting a marshmallow on a camp fire."

-Dr. Renee Bagwell

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- Achieve uniform thermal processing
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- Key: airflow uniformity

PAN Oxidation –
Critical and difficult part of the process

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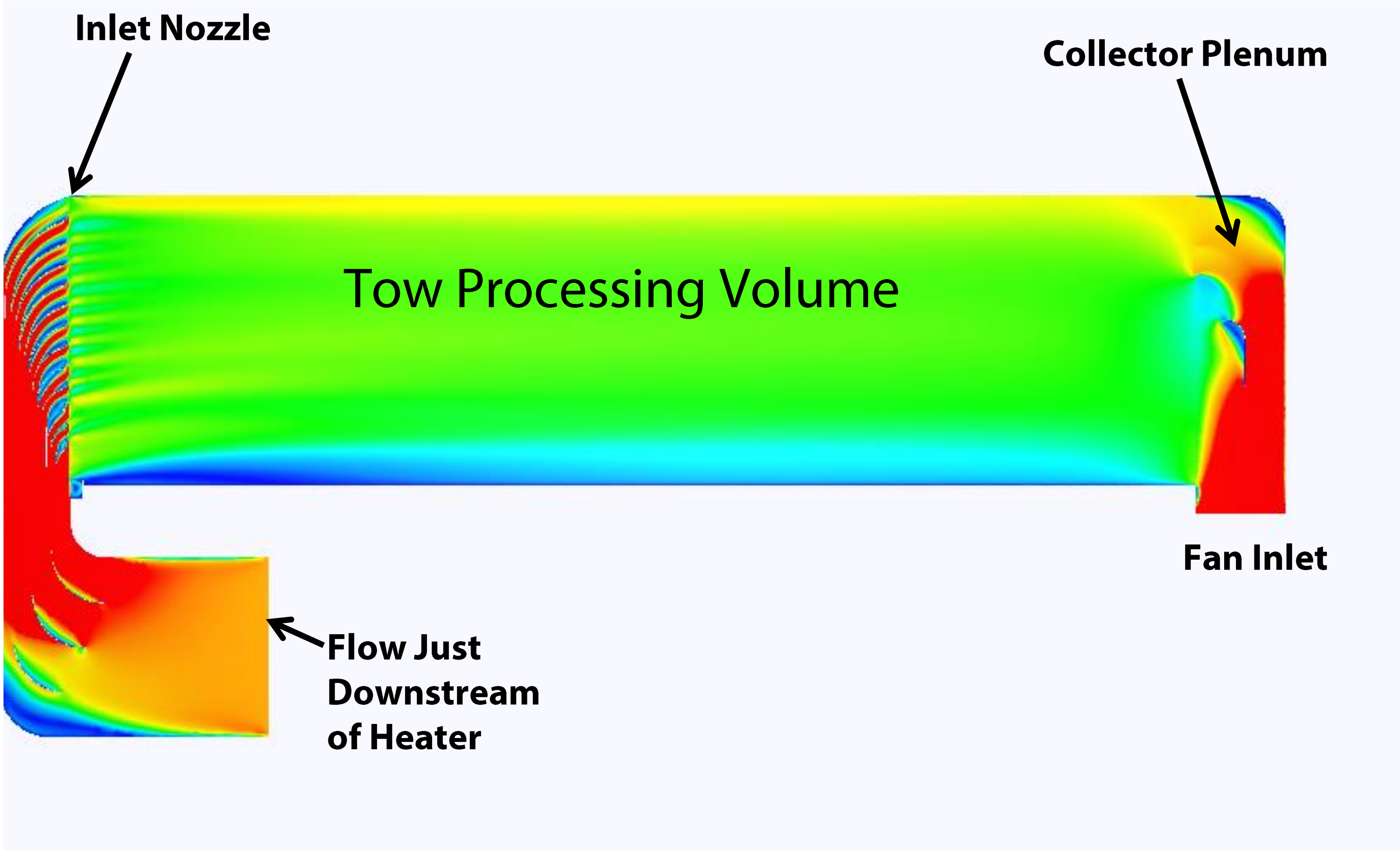
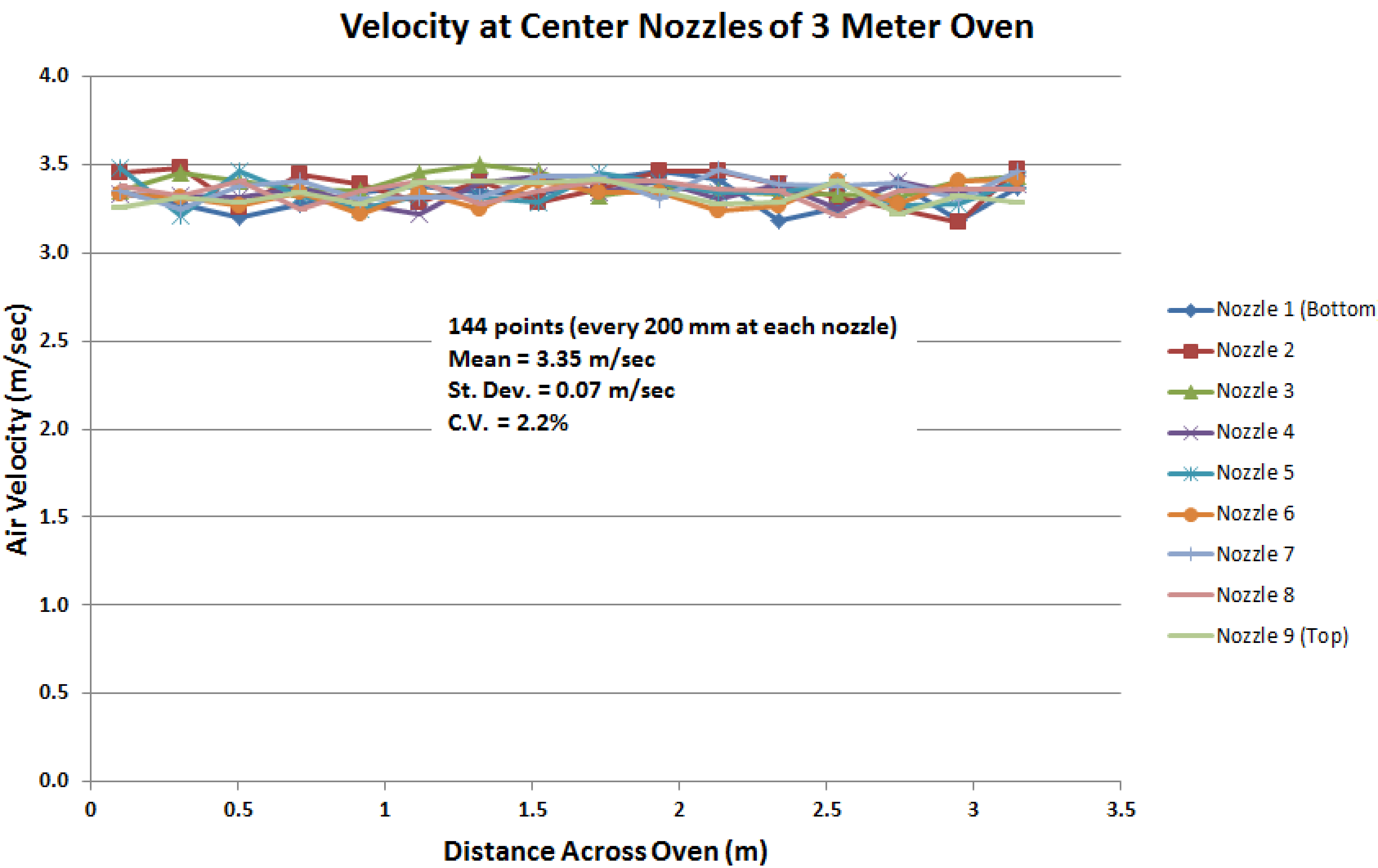
- Achieve uniform thermal processing
- Prevent runaway exotherm
- Key: airflow uniformity
  - Straight
  - Smooth
  - Even

Harper Oxidation Oven – Stable Airflow



Harper Oxidation Oven - Stable Data



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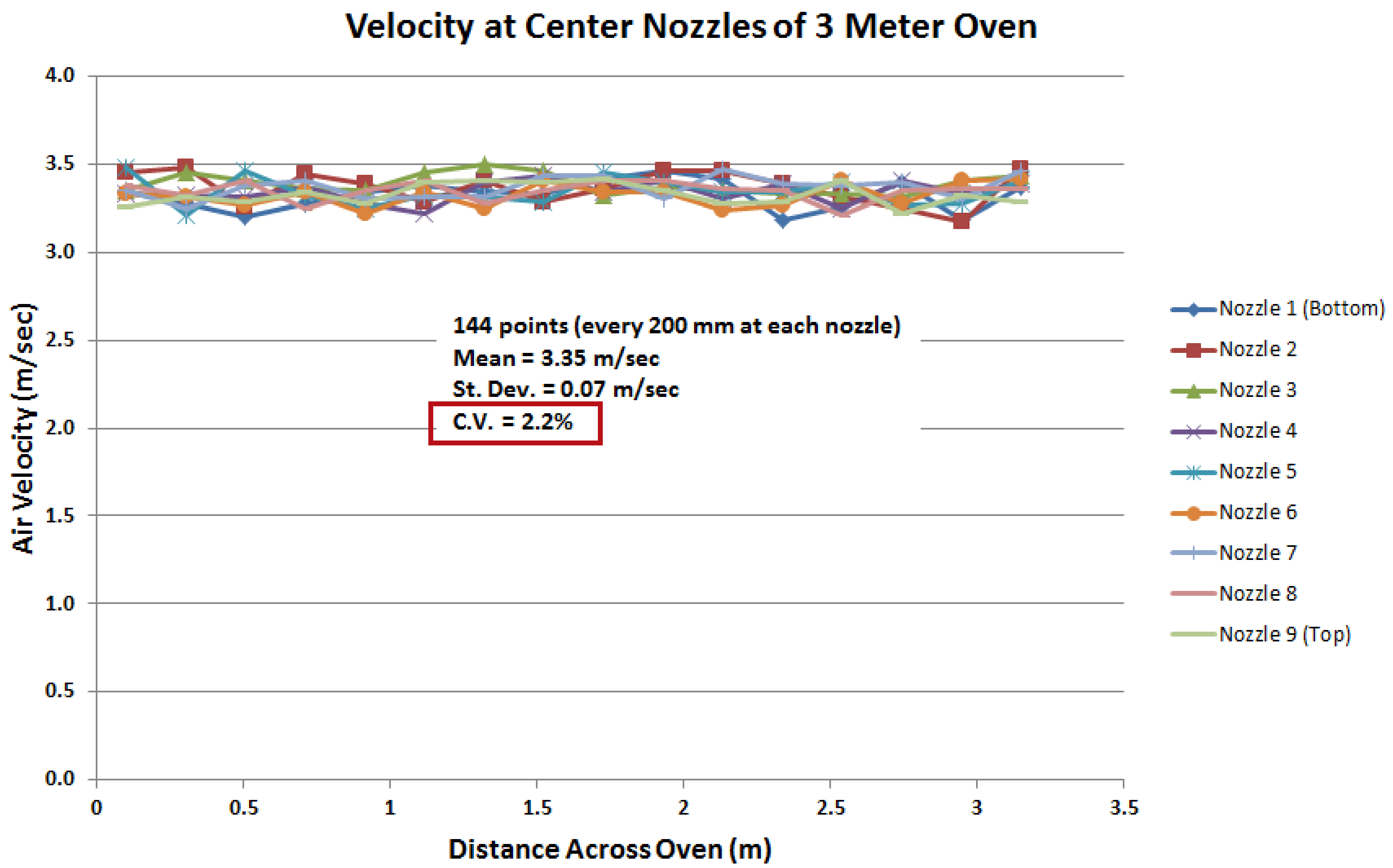
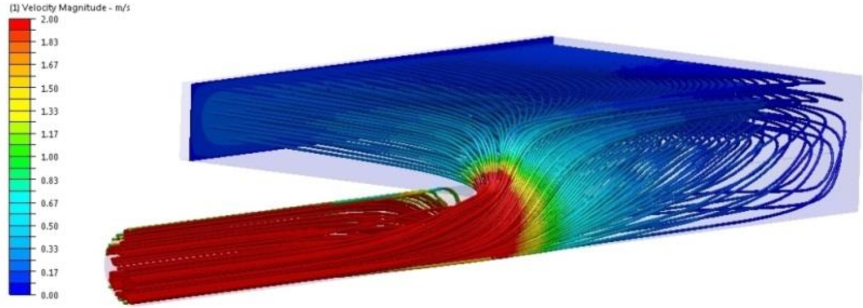


Furnaces - Reliable off-gas extraction

For vent design, Harper has extensive CFD analysis grounded in real-world experience



Width is Challenging

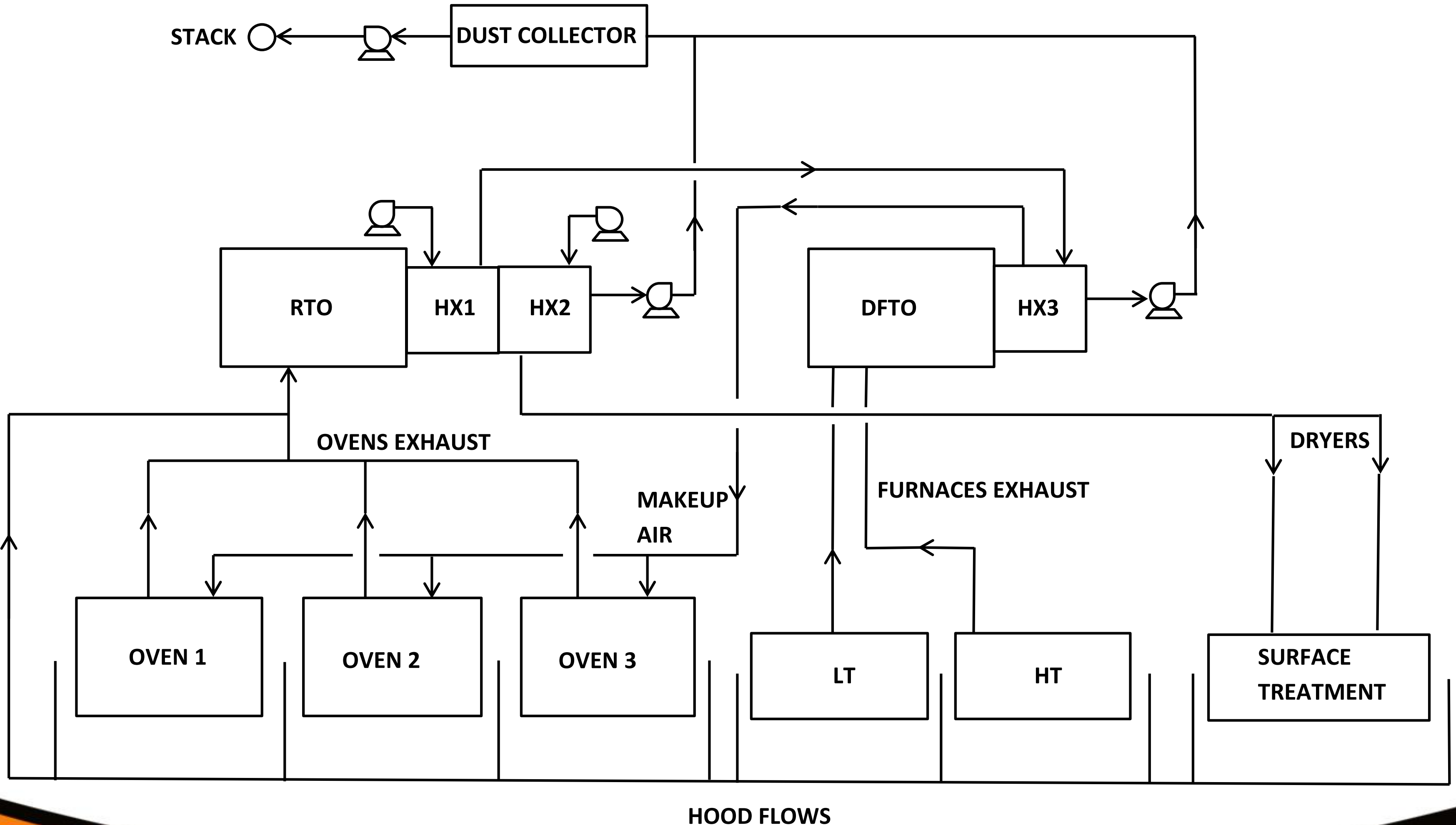
- Multiple Vent Ports?
- Dual Muffles?

Harper LT : ~5.2 meter wide tow system in final assembly,
Two (2) muffles 2.6 meter each

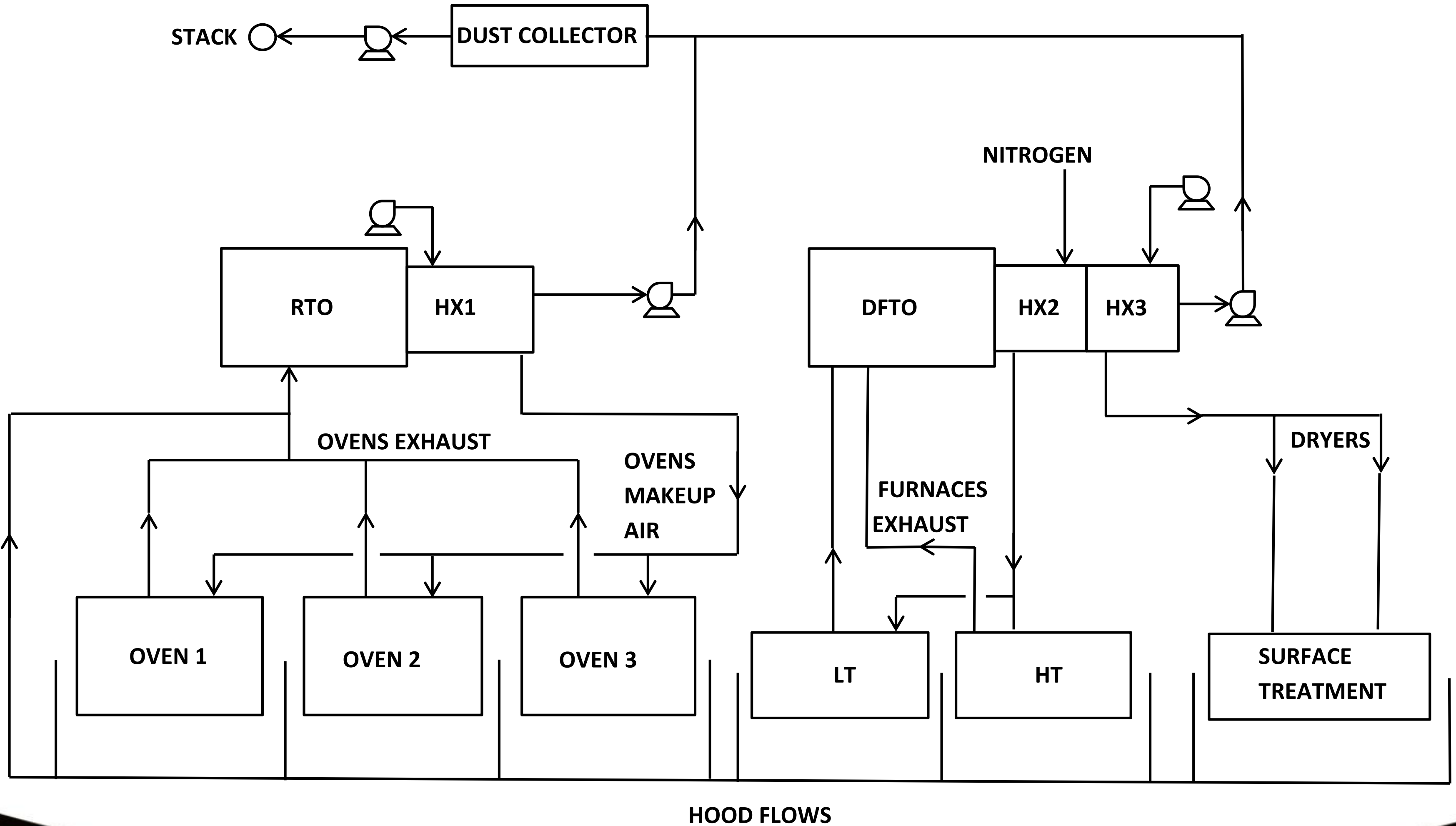
High Capacity Plant Cost Savings

10,000 Tonnes Plant Cost Scaleup Factors		
	Five 2000 TPY Lines	One High Capacity Line
CAPEX / Depreciation	5x	$5^{(0.6 \text{ to } 0.8)} = 2.6$ to 3.6x
Labor	5x	Less than 5x
Energy	5x	Less than 5x

Today Achieving Low Energy Consumption Depends on Using Recovered Heat in the Process



Another example of heat recovery – not "one size fits all"



Challenges in Scaling Up Heat Recovery

- Complexity of interconnected unit operations

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- Silica fouling – silica removal from heat exchangers

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- Tightening environmental regulations (*NOx, Particulate*)

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- Complexity of interconnected unit operations
- Silica fouling – silica removal from heat exchangers
- Plugging in furnace exhaust piping
- Tightening environmental regulations (*NOx, Particulate*)
- Piping to complex geometry as diameters increase

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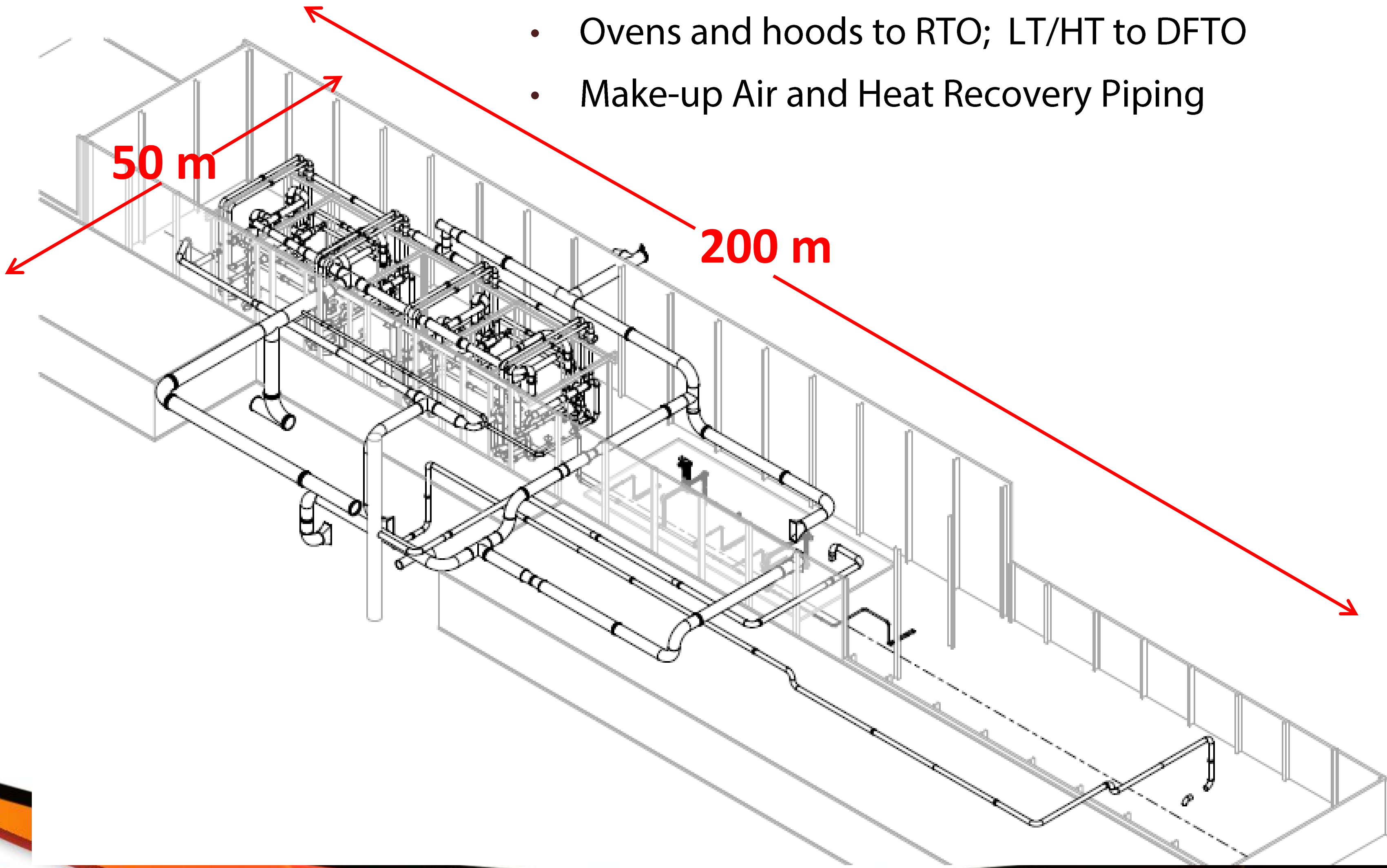
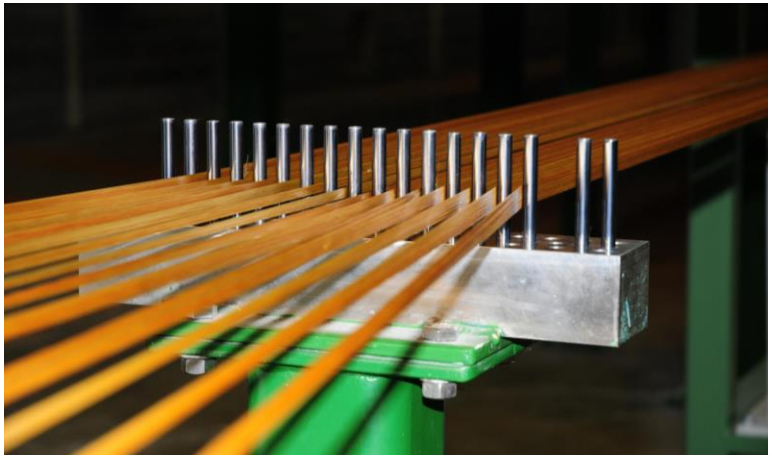
Example of CF Line Piping

- Ovens and hoods to RTO; LT/HT to DFTO
- Make-up Air and Heat Recovery Piping



Energy Savings

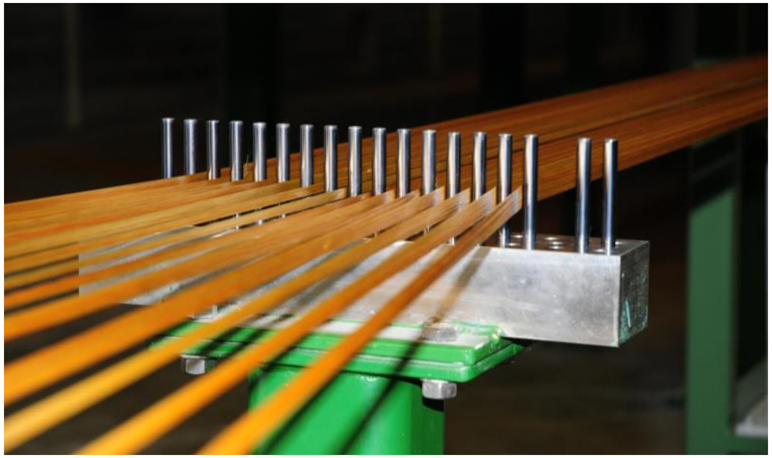
Other energy savings options that will be more important with scaled up capacities:



Energy Savings

Other energy savings options that will be more important with scaled up capacities:

- Dual tow bands in LT and HT



Energy Savings

Other energy savings options that will be more important with scaled up capacities:

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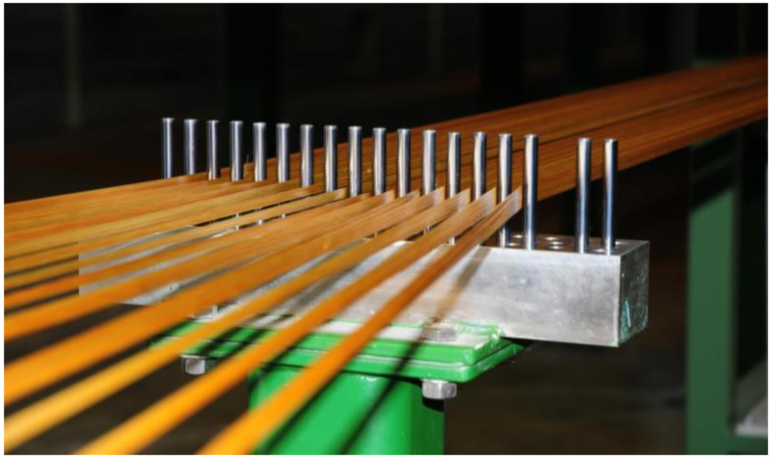
- Hybrid heating systems – use fuel or electric depending on instantaneous costs



Energy Savings

Other energy savings options that will be more important with scaled up capacities:

- Dual tow bands in LT and HT
- Hybrid heating systems – use fuel or electric depending on instantaneous costs
- Smart electric power systems that can store and retrieve power to reduce costs

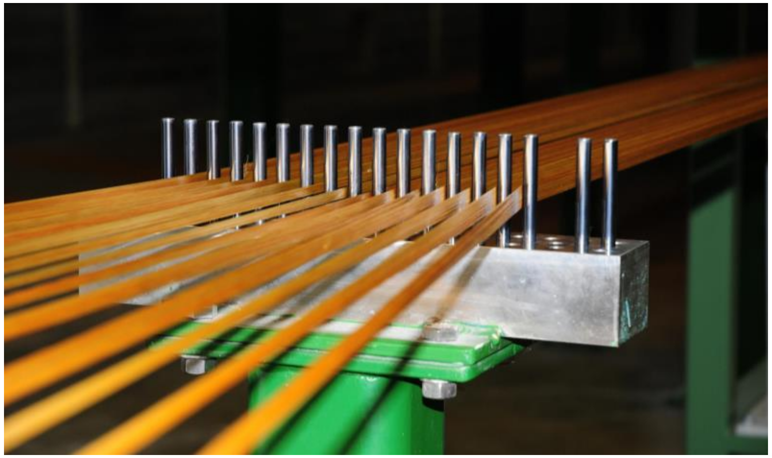
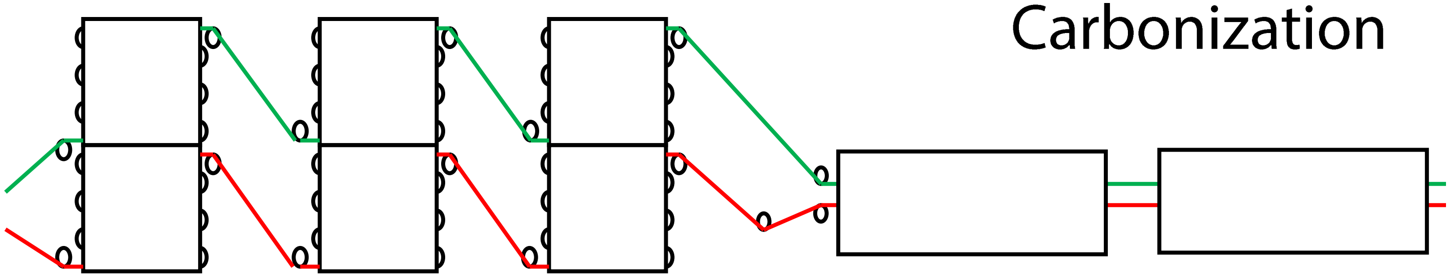


Diagram of Dual Tow Bands

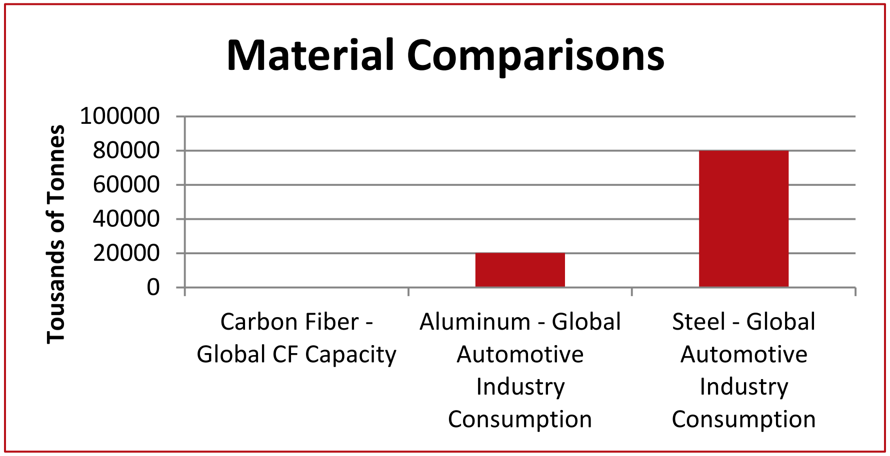


Single Plant

- Shared Controls
- Common Utilities
- Common Creels / Winders
- Etc…

Conclusions

Adoption of CFRP as an automotive material will force **rethinking of plant configuration**.



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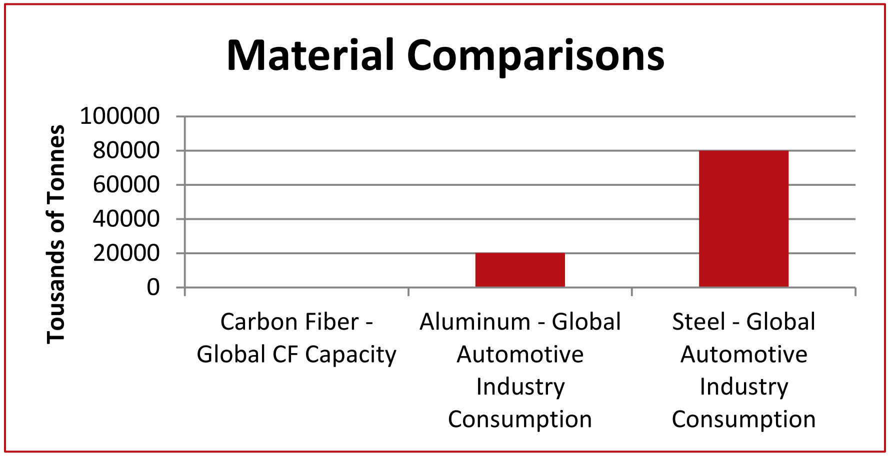

Significant **cost savings** will be realized.

Reduced CAPEX / Depreciation

Reduced Labor

Reduced energy consumption

→ Reduced $/kgCF

Conclusions

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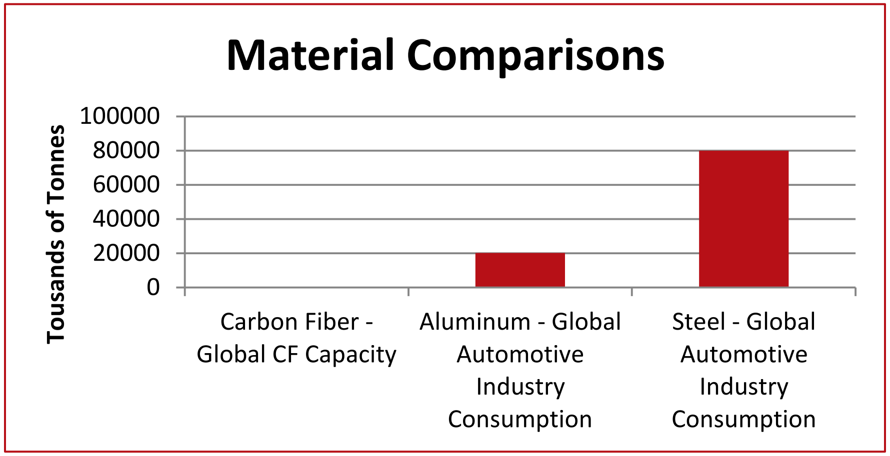

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Reduced CAPEX / Depreciation

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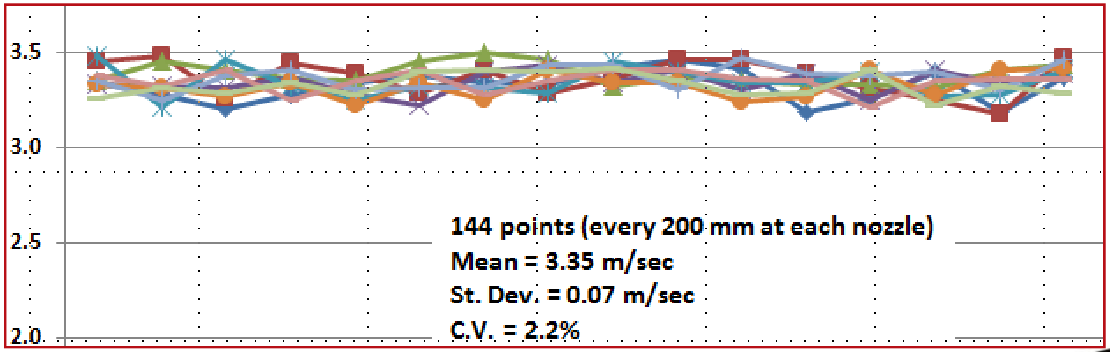
Precision and customized equipment will be paramount to success.



Thank You!

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